# Virtualizing the physical world: the on-demand room case study

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**Abstract:** Generally speaking, the *virtualization* technique allows to maximize the exploitation of available physical resources by abstracting from them a set of virtual resources that users independently own. This paper proposes to apply the virtualization technique to the built space. For this, we present a case study called *on-demand room*, where the same physical resources (space, furniture, appliances and networks) are dynamically and transparently reallocated to different apartments. Thanks to implicit interaction and automatic reconfigurations, inhabitants have the impression of owning a bigger surface than the physically available one. We present a demonstrator of on-demand room that was realized leveraging a large-scale immersive virtual reality platform and provide some perspectives for the generalization of the virtualization approach.

**Key-words:** Responsive environments, sustainability, virtualization, resource sharing

# 1 Introduction

Responsive environments have been shown to provide effective strategies to enhance the environmental performance of buildings [3]. Following this track, it is interesting to explore additional architectural possibilities inspired to and supported by computing systems. Our aim is to optimally exploit and reuse resources, especially the built surface, which is very precious in a context of urbanization that requires densification.

## 1.1 Virtualization in computer science

In computing systems, the technique called *virtualization* provides "operational flexibility and increases the utilization rate of the underlying physical hardware" [2]. This is obtained by abstracting the available physical resources and providing users with personal computing environments called *virtual machines*.

For instance, users are provided with a certain amount of data storage. If they are not using a part of it, the surplus is dynamically allocated to another user. In this way, several users virtually own an amount of storage that is globally higher of the physically available one.

## 1.2 Our challenge: virtualizing built spaces

In traditional housing, surfaces are sometimes underutilized [1]. Would it be possible to dynamically reallocate resources like space, furniture, appliances and networks, so that different inhabitants have the impression of independently owning more surface than actually available, as illustrated in Figure 1?

This paper will show through a case study that this is possible, provided that transparent reconfigurations of the physical resources happen without explicit requests or awareness of occupants.

## 1.3 Content and organization of the paper

This paper presents a case study of virtualization of built spaces called *on-demand room*, addressing the goal of optimally exploiting resources in an apartment building. In Section 2, we illustrate in detail the on-demand room, while Section 3 describes ongoing work and a work plan. Finally, Section 4 presents related work and Section 5 concludes the paper by illustrating some perspectives of generalization of the approach.

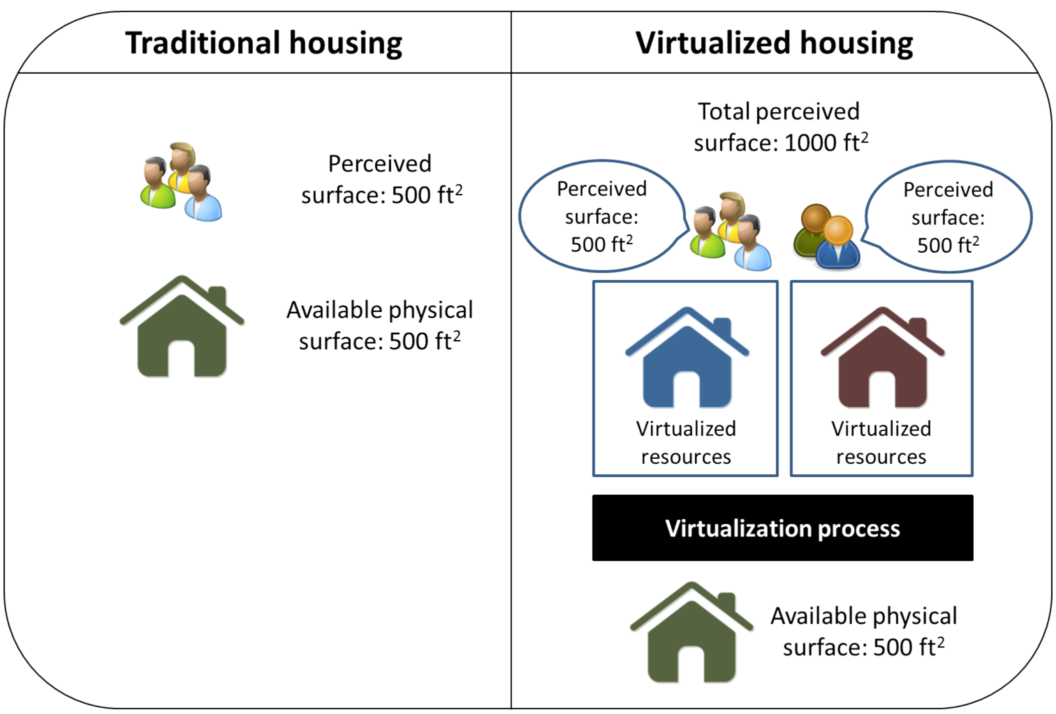


Figure 1: The virtualization of built spaces

## 2 A case study: the *on-demand room*

This section describes a case study of virtualization of built spaces in an apartment building, the *on-demand room*. The idea is that we can transparently reallocate the physical resources of a room (space, furniture, appliances, networks, etc.) to one among a set of apartments or to external users. This case study can be implemented in two different ways: with the 'traditional housing' or with the 'virtualized housing' approaches, as illustrated below.

### 2.1 Traditional housing approach to the on-demand room

In the 'traditional housing' approach, the on-demand room is like a meeting room in an office building: when the need arises, users acquire an additional space and some associated resources, like wireless Internet connection. This room can have virtually infinite functions, like providing a separate telecommuting space for an apartment's owner, few days a week; or a bedroom for a divorced parent during the week-ends, so as to host children.

Similar on-demand additional spaces are available in some residential buildings. However, they have several drawbacks, including:

- No customizations can be performed to create a sense of possession.
- Residents have to leave their dwelling and transit through common or public spaces to reach the room, thus losing the sense of intimacy of a home.
- The room layout has to be explicitly reconfigured each time by users to accommodate their own needs.

The alternative implementation of the on-demand room, which constitutes the novelty of our case study, is based on the virtualization technique, as illustrated below.

### 2.2 Virtualized housing approach to the on-demand room

We present here the implementation of the on-demand room with a virtualization approach. For ease of illustration, we will consider that the room can only be used by two apartments ("A" and "B") that physically surround it, as shown in Figure 2. Both apartments A and B *virtually* own the room, at the same time. Occupants have the impression of living in a bigger dwelling, as if they exclusively owned the room.

To produce this illusion, the physical resources of the on-demand room (space, appliances, networks, furniture, etc.) are dynamically allocated to one of the apartments at the time, so as to exclusively integrate the room to that dwelling, to all intents and purposes. The integration is obtained by connecting the devices and networks of the on-demand room with those of the apartment, and by customizing the room so that it looks and behaves as if it belonged to that dwelling.

Figure 3 illustrates the case of the resources being assigned to apartment A. As it can be noticed, the door giving onto B has disappeared and the room walls' color has changed to red, so as to reproduce the apartment's atmosphere. Also, networks and devices of the room and of the apartment are now interconnected. For instance, the room uses the

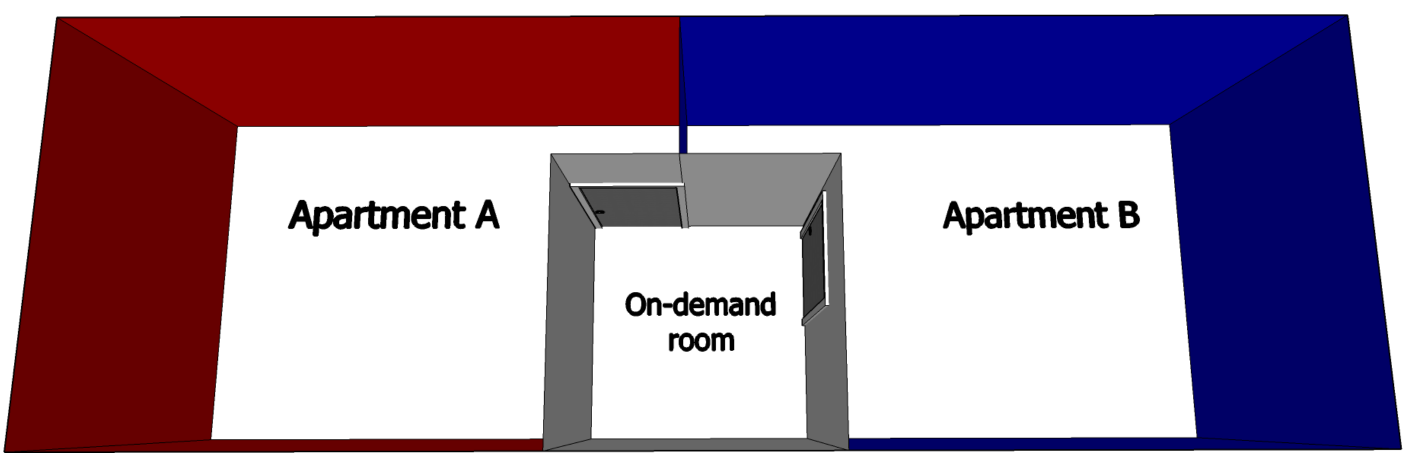


Figure 2: Plan of a building floor made of two apartments and an on-demand room in between

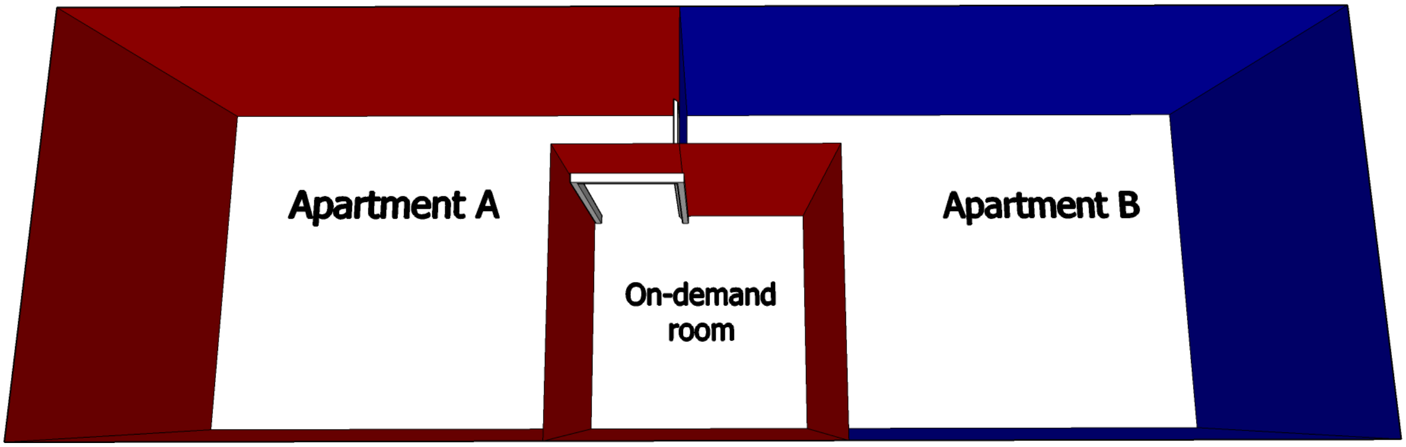


Figure 3: On-demand room assigned to apartment A

electrical and phone networks of apartment A. Furniture can also be automatically reconfigured, so as to accommodate activities and preferences of the new occupants. Figure 4 shows that the room's light bulb is controlled by the switch located in the apartment that owns the room at that moment.

## 2.3 Transparent reallocation of resources of the on-demand room

Thanks to the virtualization technique, users forget the fact that the same resources are reused for different people and different purposes. To ensure a *transparent* operation, changes in the on-demand room ownership happen without explicit requests from inhabitants.

A sensing and actuating architecture is deployed in the environment and allows reconfigurations to discreetly happen at the right moment, following the *ubiquitous computing* principles [5]. This is a human-computer interaction paradigm that states that an *implicit* dialog should be established between users and the technological system.

By observing human actions and other relevant information, the system can determine pertinent actions to perform automatically. For instance, the request for the on-demand room is implicitly formulated when occupants open the door giving onto it. This action is sensed by the system and causes space reconfigurations (e.g., the other door disappears) and network rewiring (e.g., the light switches are reprogrammed).

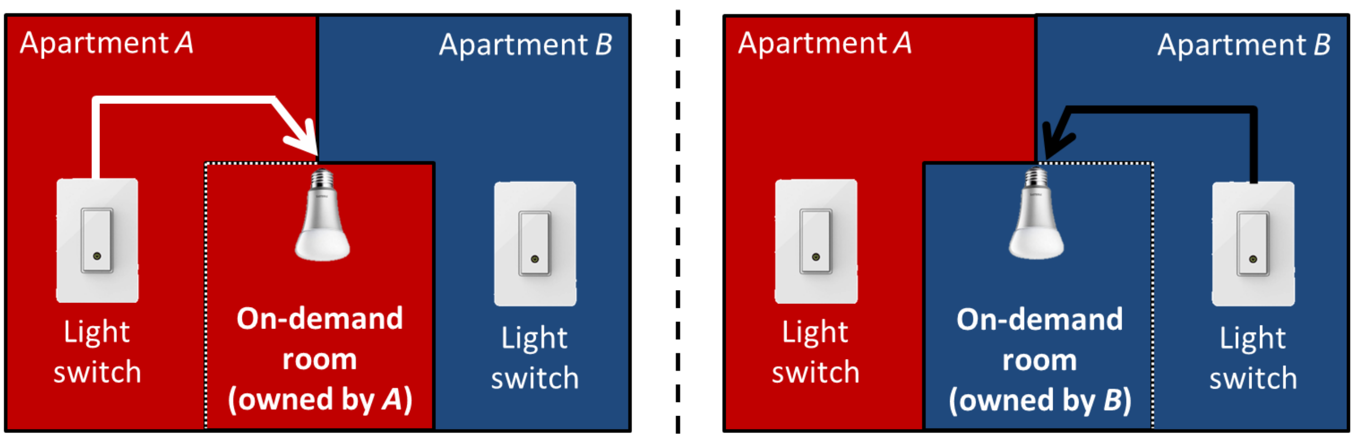


Figure 4: Light bulb controlled by A (left-hand side) or B (right-hand side), depending on who owns the room

# 3 Ongoing and future work

We realized the on-demand room case study as an interactive application in an immersive Virtual Reality (VR) platform, which we will use for evaluation purposes, as illustrated below.

## 3.1 Achieved result: a demonstrator in immersive virtual reality

We realized a demonstrator of the on-demand room case study by relying on a large VR platform dedicated to real-time and immersive interaction. Using this platform, images are rendered to a scale of 1 to 1 in three dimensions, as illustrated in Fig. 5.

We realized an architectural model of the on-demand room using SketchUp and then imported it in Unity, a game development software that, used in combination with MiddleVR, allows to deploy, visualize and interact with the model in immersive VR. The working logic of the room was implemented using Unity scripting facilities.

The demonstrator allows users to "enter" the real-size three-dimensional model and walk inside the apartments. They can open doors and observe the implied reconfigurations, as shown in Figures 6-7-8-9. A switch located in the room allows to turn on and off the light of the apartment that owns the room at that moment.

We use the demonstrator to evaluate our case study, as illustrated below.

## 3.2 Ongoing work: user experience evaluation

The immersive virtual environment allows situating users and stakeholders in realistic conditions of use. By being able to walk inside the apartments, open doors and see the effects on the on-demand room, people "feel" like the building was really there. We are currently conducting experiments to assess if users build up their own knowledge of system capabilities and elaborate their own experience leading (or not) to a transparent use.

The next step will be solving the implementation issues, so as to enable the realization of a built prototype of on-demand room, as illustrated below.

## 3.3 Future work: solving the implementation issues

There are several challenges to be addressed if we want to build an on-demand room in the real world. Some of them are:

- **Reconfiguration challenges** Architectural challenges to be addressed include changing wall colors, hiding doors, etc. Also, devices have to be reprogrammed and furniture automatically reconfigured.
- **Assessing economic feasibility** Economic questions to be answered concern the realization cost of the on-demand room and who would have to pay for it (building residents, property developers, etc.).
- **Room availability** In the current implementation of our case study, the transparency of operation is challenged if both apartments want to use the room at the same time: access will be denied to one of them. The solution can be found by designing a building that includes a pool of on-demand rooms.

# 4 Related Work

Related research activities have been given names including but not limited to *kinetic*, *responsive* [4] and *interactive* architecture [3]. Some of the active research groups and architectural design offices include the *City Science* initiative at MIT Media Lab, the *Hyperbody* group at TU Delft, the *Laboratory for Integrative Design* (LID) at the University of Calgary, the *Office for Robotic Architectural Media & The Bureau for Responsive Architecture* (ORAMBRA) and *Foxlin Architects*.

Like those initiatives, our work is part of the movement of research and experimentation that aims at raising awareness and understanding on how responsive and interactive architecture can help answering the challenges of the Anthropocene, by realizing environments that "are on the one hand sustainable and on the other hand relate to the dynamics of everyday life" [4].

Figure 5: The immersive virtual reality platform used for our demonstrator

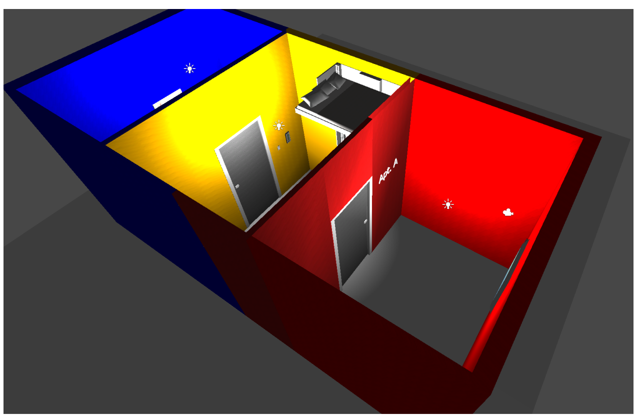

Figure 6: The three-dimensional model of the building floor, used in our demonstrator in virtual reality

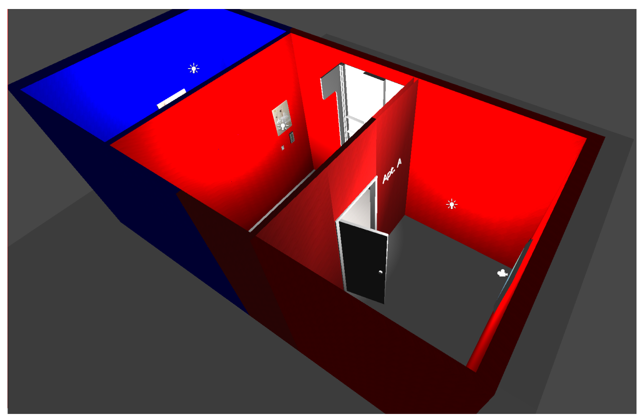

Figure 7: The model changes dynamically when the occupant of an apartment opens the room door

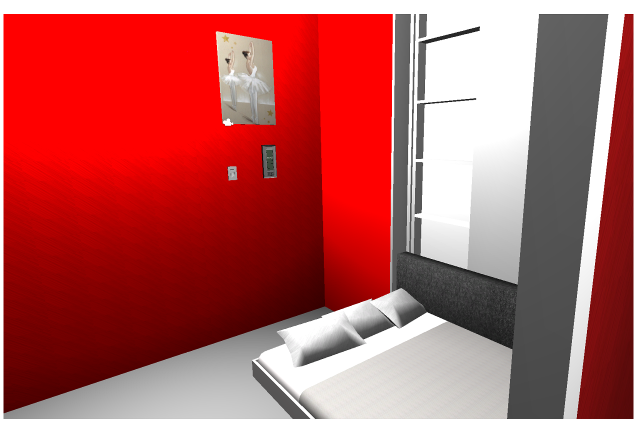

Figure 8: The on-demand room, when owned by A

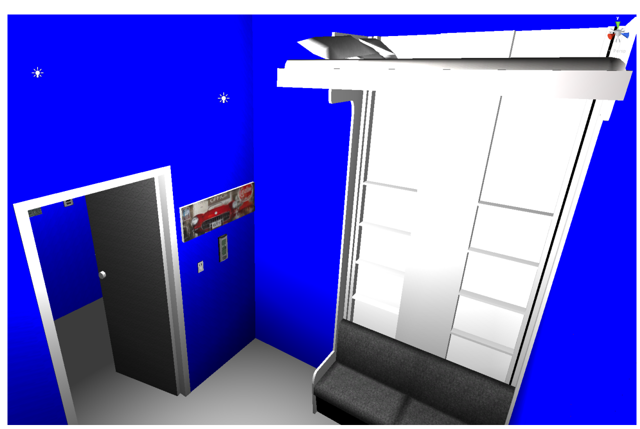

Figure 9: The on-demand room, when owned by B

## 5 Discussion

This paper presented a case study of virtualization of built spaces called on-demand room. We showed that the inhabitants of two dwellings have the impression of permanently owning a room, which is in fact time-shared among them. To provide this illusion, resources like space, furniture, appliances and networks are dynamically and transparently reallocated, thanks to implicit and thus invisible interaction with occupants.

We are aware that the virtualization of built spaces involves realization problems, e.g., we said that our prototype of on-demand room cannot manage concurrent requests from both apartments. However, what today seems difficult may be easily realized tomorrow by designing specific technologies.

Another big challenge is user acceptance: are we ready to share the physical world that surrounds us, by letting others use it when we do not need it? The growth of initiatives like coworking, cohousing and house sharing (e.g., AirBnB) seems to provide a positive answer to this question.

As computer architects, we believe that the virtualization technique can be a successful example of cross fertilization from our discipline to building architecture. Our question to ACADIA's community is the following one: *can virtualization be adopted by architects as a methodology for the design and operation of tomorrow's buildings?* We designed and realized the on-demand room as a proof of concept of this approach, as the paper showed.

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